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Opinion of the Scientific Panel on Additives and Products or Substances used in Animal Feed on the request from the Commission on the use of iodine in feedingstuffs

(Question N° EFSA-Q-2003-058)

Adopted on 25 January 2005

SUMMARY

Iodine is an essential trace element for humans and animals. It is incorporated into the thyroid hormones that have multiple functions as regulators of cell activity. Iodine deficiency affects reproductive capacity, development of brain and progeny as well as growth. Nowadays clinically evident iodine deficiency in animals is rather scarce due to feed supplementation.

The European Commission asked the European Food Safety Authority to evaluate the physiological requirements for iodine of the different animal species referred to in Directive 70/524/EEC and to advise the Commission on the possible detrimental effect on human and animal health or the environment of iodine, used at the current levels authorised under Directive 70/524/EC (4, 20 and 10 mg kg^{-1} feed for horses, fish and all other species, respectively).

The iodine requirements for animals vary between 0.1 and 1.1 mg kg^{-1} feed, being higher for cats (up to 2 mg kg^{-1} feed). Within species the requirements are influenced by physiological demands for growth, reproduction or lactation and also by dietary factors (e.g. goitrogens). In most cases iodine supplementation of daily ration is necessary due to the low iodine content of plant feedingstuffs.

Based on the limited available data the following maximum dietary iodine levels are considered as tolerated: 3 mg kg^{-1} feed for horses, 5 mg kg^{-1} feed for laying hens, higher than 60 mg kg^{-1} feed for farmed fish, 4 mg kg^{-1} feed for dogs and 6 mg kg^{-1} feed for cats. The iodine tolerance of pigs and fish is far above the EU regulations. The tolerances (proposed upper limits) are 3 to 10-fold higher than the requirement, allowing sufficient compensation for potential goitrogenic substances in feed. At present the upper safe level for dairy cow, calf, chicken for fattening, turkey, sheep, goat and rabbits can not be determined.

Higher dietary iodine supply results in increasing iodine excretion mainly by urine, but also via milk and eggs, and to a considerably smaller extent in body deposition (except sea food). Among food from terrestrial animals milk and eggs show the highest iodine concentrations. Milk iodine originates from feeding and several other sources (notably disinfectants).

All available data on iodine concentrations in foods of animal origin as well as estimates of dietary intake in Europe do not support an association between current levels of iodine feed supplementation and risks of excessive iodine intake in humans. Information considered by FEEDAP Panel also indicates that feed manufacturing practice does not make full use of the maximum levels approved.

However, the worst case scenario model calculations with milk and eggs based on the current approved maximum iodine level in feed, show that the Upper Limit for adults and adolescents could be exceeded. Reducing iodine to a maximum of 4 mg kg^{-1} complete feed for dairy cows and laying hens would result in a satisfactory margin of safety for the consumption of milk and eggs.

In farmed fish supplementation of the diet with the maximum recommended levels (20 mg iodine kg^{-1}) will still result in lower tissue concentrations than those found in wild marine fish.

FEEDAP Panel stresses the fact that iodine supplemented feeds are not the single, nor possibly the major source, of iodine in human diet. Iodine-enriched salt, supplemented food items (including iodine rich algae), iodine tablets, and some iodine enriched beverages may all contribute to the overall iodine intake.

Iodine in feed enters the environment via direct excretion of faeces and urine on pasture or spreading of sludge and slurry. This concentration is well below the background concentration and it is therefore not expected to pose an environmental risk.

Finally, FEEDAP Panel expresses the need for more and updated data on iodine requirement and tolerance in animals as well as on the actual impact of iodine supplements in feeds on total iodine dietary intake of humans.

Key words: Iodine, iodine requirement, iodine excess, iodine in food, iodine in feed.

BACKGROUND

Iodine salts are authorised under Directive 70/524/EEC concerning additives in feedingstuffs under the category "trace elements".

The Commission has the intention to review the maximum content of trace elements authorised in feedingstuffs in order to adapt these levels to the physiological requirements and to minimise negative effects on human health, animal health and the environment. In regard with these objectives, particular attention should be paid to the use of Iodine. The amount of Iodine in milk, which is consumed by humans, especially by infants, has been reported as an issue of concern for its effects on human health.

Table 1. Conditions of use of iodine salts according to Directive 70/524/EEC

N°	Additive	Description	Chemical formula	Species or category of animal and maximum levels of inclusion in feedingstuffs (mg I kg^{-1})
E 2	Iodine - I	Calcium iodate, hexahydrate	$Ca(IO_3)_2 \cdot 6H_2O$	Equines: 4 (total) Fish: 20 (total) Other species or categories of animals: 10 (total)
		Calcium iodate, anhydrous	$Ca(IO_3)_2$	Equines: 4 (total) Fish: 20 (total) Other species or categories of animals: 10 (total)
		Sodium iodide	NaI	Equines: 4 (total) Fish: 20 (total) Other species or categories of animals: 10 (total)
		Potassium iodide	KI	Equines: 4 (total) Fish: 20 (total) Other species or categories of animals: 10 (total)

TERMS OF REFERENCE

- What are the real physiological requirements for iodine of the different animal species referred to in Directive 70/524/EEC in regard to this trace element?
- Does iodine, used at the current levels authorised under Directive 70/524/EC, have detrimental effect on human or animal health or on the environment?

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ASSESSMENT

1. Introduction

Iodine occurs in nature as iodide and iodate. Its mineral forms occur ubiquitously in igneous rocks and soils, most commonly as impurities in saltpetre and natural brines. It is liberated by weathering and erosion, and, because of its water-solubility, it leaches by rainwater into surface water, the sea and the oceans, soils in mountainous regions becoming low in iodine. In many areas of the world the surface soil becomes progressively poorer in iodide through leaching processes (Fuge and Johnson, 1986). Liberated elemental iodine sublimates into the atmosphere because of its volatility and is precipitated by rainfall onto the land surface. Iodides in the sea accumulate in seaweeds, sea fish and shellfish. On land, small amounts of iodide are taken up by plants, which do not have a requirement for this element. Iodine content of water decreases with the increasing distance from sea (Anke *et al*., 1993; Underwood and Suttle, 2001).

Iodine is an essential trace element for animals and humans. The only known role of iodine in the metabolism is its incorporation into the thyroid hormones, thyroxine (T_4, 3,5,3',5'-tetraiodothyronine) and triiodothyronine (T_3, 3,5,3'-triiodothyronine) as well as the precursor iodothyrosines. Both hormones have multiple functions as regulator of cell activity (energy metabolism) and growth, transmitter of nervous stimuli and as an important factor for brain development (see review by Delange and Hetzel, 2003).

The mean iodine concentration in animal tissues is about 0.1 mg kg^{-1} (Jongbloed *et al*., 2002). T_4 contains about 65 % of the body iodine (Mc Dowell, 2003). The concentration in tissues other than thyroid is rather low. Iodide is distributed in the extracellular compartment. The protein bound iodine fraction in blood plasma which consists mainly of the thyroid hormones depends on age (increased in young animals) and on the intensity of the metabolism.

The major natural sources for animals (and humans) are iodides in feed (and food) and water. The absorption of iodine takes place in form of iodide in the total gastrointestinal tract, but mainly in the small intestine (Ketz, 1989), and in ruminants in the rumen (Underwood, 1977). The absorption rate is about 80-92 % (Jongbloed *et al*. 2002, SCF 2002).

Iodine is predominantly excreted via the kidneys as iodide. Iodide in faeces is mainly of endogenous origin due to high absorption. Iodide is also excreted in milk and eggs by active transport.

Iodine deficiency leads to morphological and functional changes of the thyroid gland and reduces the formation of thyroxin. Deficiency may be caused by insufficient iodine intake and/or by other factors such as goitrogens in feedingstuffs (e.g. glucosinolates). Iodine intoxication is rare (Hemken, 1970).

1.1. Deficiency

Iodine deficiency in animals reduces the production of thyroid hormones as in humans. The consequences are a slowing down of many metabolic processes, especially oxidation at cellular level. Iodine deficiency also reduces the capacity of reproduction as well as growth and development of the progeny (Pandav and Rao, 1997; Pittman and Pittman, 1997).

More precisely, the main unspecific manifestations of iodine deficiency are (Pittman and Pittman, 1997):

a) General: sluggishness, decreased feed intake, decreased body weight gain of young animals, reduced production/performance, dry hair/wool, puffy appearance, decreased resistance to cold, preference to heat, decreased resistance to infections, stunted growth, dwarfism and goiter.

b) Reproduction failure: decreased reproductive frequency (mating), decreased male libido and fertility, fetal goiter, increased incidence of intrauterine mortality and abortion, prolonged gestation, increased stillbirths, retention of fetal membranes and retarded resorption of the yolk sac. Fetal death can occur at any stage of gestation. Often the mother will appear not affected (Hemken, 1970). Under conditions of marginal or deficient dietary iodine the maternal thyroid gland becomes extremely efficient in the removal of iodine from plasma and in the recovery of iodine from the degradation of released thyroid hormone and thyroglobulin. This leaves little iodine for the fetal thyroid gland, and the fetus becomes hypothyroid. Scott (1960) reported fetal resorption, while estrus and libido were unaffected in cats.

The effects of iodine deficiency on development, particularly of fetal brain have been extensively investigated because of its relevance to the human problem of endemic cretinism. Extensive experimental studies were conducted in rat, sheep and marmoset with less than 10 µg kg^{-1} feed (Review by Delange and Hetzel, 2003). In particular, sheep on experimental iodine deficient feed providing an intake of $\leq$ 0.5 µg iodine kg^{-1} bw per day showed more abortions, stillbirths and lower fetal body weights, reduced or even complete absence of wool growth, retarded bone development, skull deformities, reduced brain weight and reduced brain cell numbers. The same deficiency effects were seen in marmoset on 1 µg iodine kg^{-1} bw per day (Hetzel and Hay, 1979).

The geographic pattern of iodine deficiency in farm animals appears to follow the pattern of human iodine deficiency around the world (Pittman and Pittman 1997). Goiter generally occurs in farm animals where ever human goiter is endemic (Bedi, 1997; Underwood and Suttle, 1999). Similarly, endemic goiter in wild animals (enzootic goiter) has been reported with a geographic distribution superimposable to the one of human endemic goiter (Review by Orts *et al*., 1971).

In summary, iodine deficiency affects thyroid function in animals in the same way as in humans. In all age groups, iodine deficiency decreases the production of thyroid hormones and subsequently the general metabolism and oxidation processes. In addition, iodine deficiency occurring during the critical period of fetal and early postnatal brain development results in severe thyroid failure and irreversible brain damage.

2. Iodine Requirements of Animals

One of the first estimates of the minimum iodine required by farm animals was performed by Mitchell and McClure in 1937. This study served still in 1999 as basis for deduction of dietary minimum requirements by Underwood and Suttle being between 0.05 mg and 0.10 mg iodine kg^{-1} feed dry matter (DM) for pigs, poultry and sheep.

The iodine requirements for various food producing livestock species as published by different scientific bodies are presented in Table 2. They vary between 0.1 and 0.8 mg kg^{-1} feed DM (1.2 mg for fish), but are higher for dogs and cats (up to 2.3 mg kg^{-1} feed DM). Within species the requirements are influenced by physiological events such as growth, reproduction or lactation (iodide loss via milk), at maintenance level by the integrity of thyroid structure and function (Underwood and Suttle, 1999). Iodine requirements are also influenced by environmental factors. The rate of secretion of the thyroid hormones in ruminants has been shown to be inversely related to environmental temperature (McDowell, 2003).

Cyanogenic compounds are goitrogenic because they produce thiocyanate which impairs iodine uptake by the thyroid gland. Therefore dietary iodine supply has to be increased when rations containing goitrogens (e.g. glucosinolates) are fed.

Table 2. **Iodine requirements (NRC) or allowances (GfE) of domestic animals (mg)**

	National committees (scientific bodies)					
	GfE (Gesellschaft für Ernährungsphysiologie)			NRC (National Research Council)		
Animals/categories	kg^{-1} feed DM	kg^{-1} feed 88 % DM	Year	kg^{-1} feed DM	kg^{-1} feed 88 % DM	Year
<u>Ruminants</u>						
Dairy cow	0.50	0.44	2001	0.50	0.44	2001
Growing bull	0.25	0.22	1995	0.50	0.44	1996
Heifer	0.25	0.22	2001	0.25	0.22	2001
Sheep				0.1-0.8	0.1-0.7	1985
Goat	0.3-0.8	0.3-0.7	2003			
<u>Pigs</u>						
Growing pig	0.15	0.13	1987	0.16	0.14	1998
Breeding sow	0.5-0.6	0.4-0.5	1987	0.16	0.14	1998
Boar (sexually active)	0.5-0.6	0.4-0.5	1987	0.16	0.14	1998
<u>Horses</u>	0.1-0.2	0.1-0.2	1994	0.1-0.5	0.1-0.4	1989
<u>Poultry</u>						
Immature Layer	0.4	0.35	1999	0.33-0.35	0.29-0.31	1994
Layer	0.5	0.44	1999	0.32-0.49	0.28-0.39	1994
Broiler	0.5	0.44	1999	0.35	0.31	1994
Turkey	0.5	0.44	2004	0.4	0.35	1994
<u>Fish</u>						
Channel Catfish (*Ictalurus punctatus*)				1.2	1.1	1993
Pacific Salmon (*Oncorhynchus spp.*)				0.7-1.2	0.6-1.1	1993
Rainbow trout (*Oncorhynchus mykiss*)				1.2	1.1	1993
<u>Dog (m, g, r)</u>				0.9[a]	0.8	2003
<u>Cat (m, g, r)</u>				2.3[b]	2.0	2003

[a] Energy density: 16.75 MJ ME kg^{-1} DM [b] Energy density: 18 MJ ME kg^{-1} DM
m: maintenance g: growth r: reproduction
DM = Dry Matter

2.1. Definitions

Nutrient requirement: the individual demand of a specific nutrient under defined optimal conditions. Data on requirement do not include a margin of safety.

Nutrient requirements are not suitable for calculating rations for groups of animals kept under different conditions therefore, recommendations should be used in practice.

Recommendation or ***Allowance***: estimate of the necessary nutrient supply to meet the average gross demand of the population under field conditions plus a safety factor considering the individual variability and nutrient bioavailability due to the specific nutrient compound and potential interactions between nutrients.

Allowances or recommended dietary concentrations for iodine consider interactions with other nutrients (e.g. Zn and Se deficiency), variability in bioavailability, iodine loss from feed and premixes (storage at high temperature and humidity, mixing, pelleting) or variable iodine concentrations in feedingstuffs (soil), partially also the potential presence of dietary goitrogenes.

Tolerable Upper Intake Level: the highest dietary level of a nutrient/the highest daily nutrient intake (UL) that is likely to pose no risk of adverse health effects for almost all individuals in the general population of an animal species/category or humans.

2.2. Ruminants

2.2.1. Cattle

The daily thyroxine production of growing and mature non-lactating cattle is 0.2 to 0.3 mg thyroxine per 100 kg body weight (bw), which contains 0.13 to 0.2 mg iodine (Miller *et al*., 1988). Under consideration of iodine utilization by the thyroid gland and the recycling of iodine from degraded and previously secreted thyroxine (Miller *et al*., 1975), about 0.6 mg iodine per 100 kg bw day^{-1} is required to meet the iodine requirements for thyroxine synthesis.

Assuming the dry matter intake of a 600 kg non-lactating pregnant cow is 1.8 % of bw, the diet of that cow must contain in 10.8 kg DM 3.6 mg iodine corresponding to about 0.3 mg iodine kg^{-1} feed DM (NRC, 2001).

In highly lactating cows the rate of thyroxine production increases by about 2.5 (Sorensen, 1962). The iodine requirement of lactating cows is therefore 1.5 mg 100 kg^{-1} bw or 9 mg day^{-1} for a 600 kg cow. Assuming a DM intake of 20 kg day^{-1} (3 to 3.5 % bw), the diet of a lactating cow should contain about 0.5 mg iodine kg^{-1} DM (GfE, 2001; NRC, 2001; see Table 2).

Iodine requirements for growing bulls and heifers are similar to pregnant and non-lactating cows. However, higher values (0.5 mg kg^{-1} DM) are recommended for intensively growing bulls (NRC, 1996; Table 2).

2.2.2. Sheep and Goats

A considerable range is given by scientific bodies for iodine requirements/ recommendations of sheep and goats (0.1-0.8 mg kg^{-1} DM, Table 2). A lack of experimental data and the differences of requirements for maintenance, growth and lactation could serve as explanation for this range.

In the absence of goitrogens 0.5 mg iodine kg^{-1} DM should be adequate for pregnant and lactating sheep and goats, but for non lactating animals allowances might be as low as 0.15 mg iodine kg^{-1} DM (ARC, 1997).

In the presence of goitrogens dietary iodine concentration should be increased to as much as 2 mg kg^{-1} DM (GfE, 2003).

2.3. Pigs

According to the estimates of the NRC (1998) the iodine requirement of growing pigs (5 to 120 kg bw), gestating and lactating sows and sexually active boars is 0.14 mg iodine kg^{-1} feed (90 % dry matter; around 13.7 MJ ME kg^{-1}). However the data published by the NRC (1998) show some discrepancies concerning the dietary iodine requirement of lactating sows. In the nutrient requirement tables a minimum requirement of 0.14 mg iodine kg^{-1} diet (see Table 2) is given, whereas the data published by Andrews *et al.* (1948) are cited in the text, which might indicate an iodine requirement of 0.35 mg kg^{-1} diet for the lactating sow. In contrast, ARC (1981) and GfE (1987) clearly differentiate between lactating sows and other swine categories. According to the ARC (1981) the iodine allowance of lactating sows as well as of breeding sows and sexually active boars is 0.50 mg kg^{-1} feed DM, considerably higher than the allowances of growing pigs.

The GfE (1987) also considered the high iodine loss with the milk. Based on a mean milk production of 7 L day^{-1} and a concentration of 0.47 mg iodine kg^{-1} mature milk (3.3 mg iodine net requirement for milk production) the GfE (1987) recommends an iodine content of 0.6 mg kg^{-1} complete feed. However, in a more recent study, Schöne *et al.* (2001) found only 0.054 to 0.168 mg iodine kg^{-1} milk in sows fed diets (basal concentration of 0.025 mg iodine kg^{-1} feed) without glucosinolates supplemented with 0 to 0.6 mg iodine kg^{-1}. This corresponds to an iodine excretion in the mature milk of 18 - 45 % of the iodine intake. The authors suggested that grain/soy bean meal diets for lactating sows should be supplemented with 0.6 mg iodine kg^{-1} to (i) guarantee that 0.1 mg iodine kg^{-1} milk are exceeded and (ii) to ensure a balance between iodine intake and loss. Diets containing up to 2 µmol glucosinolates kg^{-1} should be supplemented with at least 1 mg iodine kg^{-1} to compensate for the higher urine losses (Schöne *et al.*, 2001).

The current requirement data for growing pigs and sows are based on older studies (e.g. Cromwell *et al.*, 1975; Andrews *et al.*, 1948). Therefore, present requirement data do not consider higher performance (daily gain, number of piglets/sow) and lower feed intake of the modern high lean pig. However, a very recent study (Berk *et al.*, 2004) does not support this criticism. In a dose response study barley/wheat/soy bean meal diets with analysed iodine contents of 0.17, 0.41, 0.99, 2.20 and 4.38 mg kg^{-1} feed were fed to groups of 14 growing pigs (27.1-118.0 kg bw) each. No significant differences could be observed in body weight gain (837, 819, 811, 851 and 867 g day^{-1}, respectively) and feed efficiency (37.4, 38.3, 37.8, 36.4 and 36.0 MJ ME kg^{-1} gain, respectively).

2.4. Horses

Recommendations of the NRC (1989) as well as GfE (1994) are all in the range of 0.1 to 0.2 mg iodine kg^{-1} diet. For reproduction the value is increased by 60 %. If goitrogenic substances are part of the diet, the iodine content has to be increased two to three times. A factorial calculation for ponies lead to requirement values of 7 µg iodine kg^{-1} bw day^{-1} (Wehr *et al.*, 2001). This is about double the above recommendations.

2.5. Poultry

While NRC established in 1984 and confirmed in 1994 0.3 mg iodine kg^{-1} diet for laying and breeding hens and 0.35 for broilers as the requirement, GfE (1999) suggests 0.5 mg iodine kg^{-1} diet for laying hens and broilers as allowance.

No dose-response studies exist for turkeys. Therefore, iodine recommendations for fattening turkeys were adopted from iodine recommendations for broilers. About 0.5 mg iodine kg^{-1} feed (88 % DM) is considered to be sufficient, even for intensively growing turkeys (GfE, 2004).

2.6. Rabbit

No minimum requirement of iodine for rabbits has been established. At least 0.2 mg iodine kg^{-1} diet is recommended (Cheeke, 1987).

2.7. Fish

Information on dietary iodine requirement of fish is scarce. Although fish can meet their iodine requirement from both feed and water, the dietary iodine requirement of fish seems to be higher than for most terrestrial animals. NRC (1993) gives the iodine requirement of different fish species between 0.6 and 1.1 mg iodine kg^{-1} diet (see Table 2). Chinook salmon *(Oncorhynchus tshawytscha)* parr have a higher iodine requirement than fingerlings due to higher thyroid activity during smoltification (NRC, 1993). According to Lall (1979) referring to the same study with Chinook salmon (Woodall and LaRoche, 1964) the iodine requirements for parr and fingerling are 1.1 and 0.6 mg kg^{-1} dry feed, respectively. The requirements for iodine varies depending on fish species and physiological state (e.g. spawning). Nutrient loss from feed by leaching is a frequent problem in fish nutrition.

The iodine content is generally high in diets for carnivorous fish, which are based mainly on fish meal and other marine by-products (0.8-8 mg iodine kg^{-1} DM; Underwood and Suttle, 2001). The mean iodine content in commercial fish feed was reported to be 4.6 mg kg^{-1}, and ranged between 1.2-10.5 mg kg^{-1} (n=95, Julshamn *et al.,* 2001). Studies with rainbow trout indicated, that high levels of supplemented iodine (1 and 2 mg kg^{-1} diet) can partially compensate for the adverse effects of glucosinolates (2.2 - 7.3 mmol kg^{-1}) on growth rate and T_3 level (Burel *et al.*, 2001).

2.8. Dog

The NRC recommendations (2003) for dogs are 52.5 µg iodine MJ^{-1} metabolisable energy (ME) (0.22 µg iodine $kcal^{-1}$ ME), corresponding to about 0.9 mg iodine kg^{-1} feed DM.

2.9. Cat

There are very few data available on which to base a recommendation for iodine supply in cats. In 2003 NRC recommended 130 µg MJ^{-1} ME (0.55 µg $kcal^{-1}$ ME). This corresponds to 2.3 mg iodine per kg DM containing 18 MJ^{-1} ME.

2.10. Conclusion

Summarizing the requirement data it can be concluded that slowly growing ruminants, pigs and horses need about 0.2 (0.1-0.3) mg iodine kg^{-1} feed. High performance (lactation, fast growing, sexual activity) may double the requirement up to 0.5 mg iodine kg^{-1} feed. As a result of intensive breeding progress, poultry needs between 0.4 and 0.5 mg iodine kg^{-1} feed. Fish requirements are higher, about 1 mg iodine kg^{-1} feed. Among pets, cats show the highest requirement with 2 mg iodine kg^{-1} feed, and dogs 40 % of that figure (0.8 mg kg^{-1}).

Dietary cyanogenic compounds may increase the requirement by the factor two or more, depending on their dietary level. The physiological stage of the animal also influences the iodine requirement. High performance is associated with higher activity of the thyroid gland. Leaching of fish diet also deserves attention demanding for a compensatory increased dietary iodine concentration. Moreover, the available information does not always permit an adequate differentiation between requirement data and allowances (recommendations).

Finally, it should be noted that the basic data for the current knowledge on iodine requirement were mostly obtained long years ago. Significant scientific contributions to our knowledge in the last two decades, using more advanced analytical techniques are rather scarce. Iodine requirement in major food-producing species may have changed due to the significant advances in breeding methods, leading to higher growth rates and a higher meat proportion in the body as well as a higher milk yield. Feed manufacturing techniques also deserve consideration. Most of the available studies do not consider the potential loss of iodine in feed from manufacturing until final consumption. Overall, there is a need for establishing more up-to-date information of the iodine requirement in farm animals. In particular, more data on dose-response relationships in major food producing species would be required to assess the iodine requirements and allowances in high yielding animals with the desired accuracy.

3. Sources of iodine for animals

Concentrations of iodine in forages are extremely variable and depend on the iodine content of the soil, which is inversely related to the distance from the sea. Iodine concentrations of some common feedingstuffs range from 0 to 1 mg kg^{-1} except fish meal (up to 3.3 mg kg^{-1} DM). Iodine contents of some feedingstuffs are shown in Table 3.

In many European regions, iodine concentration in forages is generally low enough to result in a deficiency of iodine unless iodine is supplemented to the diet.

Iodides of sodium, potassium and calcium iodate are authorised sources of iodine for supplementation (Table 1).

3.1. Conclusion

In most cases, iodine supplementation of practical diets for food producing and companion animals is necessary. To FEEDAP Panel's best knowledge, current practice uses only a small portion of the allowed levels depending on the animal species (1-2 mg kg^{-1} terrestrial farm animal feed, and up to 10 mg kg^{-1} for fish feed).

Table 3. **Iodine content of some common feedstuffs**
(DLG, 1973; Jeroch *et al*., 1993; NOVUS-Tables 1996)

Feedstuffs	mg kg^{-1} DM	Feedstuffs	mg kg^{-1} DM
Roughages		Hay	
Forages		Alfalfa, growing	0.21
Grass		flowering	0.24
Orchard-grass (*Dactylis glomerata*)	0.25	Red clover, growing	0.36
Pasture, growing	0.70	flowering	0.26
Raygrass, growing	0.39	Pasture grass flowering	0.27
flowering	0.17	Straw	
Alfalfa, growing	0.25	Barley	0.35
Red clover, growing	0.36	Oat	0.32
		Wheat	0.55
Ref. NOVUS-Tables 1996 (Range of worldwide data sources)			
Concentrates			
Seeds		Feeds of animal origin	
Barley	0.05-0.40	Blood meal	0.35-0.90
Maize	0.05-0.38	Fish meal	1.5-3.3
Oat	0.10-0.20	Meat and bone meal	0.8-1.5
Peas	0.15-0.30	Skimmed milk powder	0.4-1.2
Rye	0.10-0.20		
Soy bean	0.05-0.08		
Wheat	0.05-0.60		
By-products		Roots and tubers	
Maize distillers grain	0.04-0.10	Carrots	0.35
Molasse (sugar beet)	0.75-1.6	Fodder beets	0.36
Rape seed meal	0.65	Potato, steamed	0.12-0.22
Soybean meal	0.20-0.60		
Sugar beet pulp, molassed	0.5-1.8		

The EU regulations banning the use of blood meal and meat and bone meal has resulted in reduction of protein sources of animal origin in feed and a concomitant increase of vegetable (e.g. soy, rapeseed or cereal) protein sources. Since plant feedingstuffs have generally lower iodine content, an increased need for iodine supplementation may result. In particular, the use of rapeseed may lead additionally to a higher need for iodine supplementation because of its glucosinolate content.

4. Effects of Excess Iodine on Animal Health

4.1 Cattle

For beef cattle the maximum tolerable level was set by the NRC (1980) at 50 mg kg^{-1} diet. Olson *et al.* (1984) reported a case study based on six herds of dairy cattle with a preceding supply of iodine in the range of more than 68 – 600 mg per animal and day for 1 month up to 7 years. Coughing, naso-ocular discharge and pneumonia in calves were recorded as predominant clinical signs. Clinical symptoms disappeared during 4 weeks after reduction of iodine supply to 12 mg per animal and day (approx. 0.5 mg iodine kg^{-1} DM). However, the data are not sufficiently conclusive for an upper tolerated iodine level in feed.

High concentration of dietary iodine also increases iodine concentration in milk (Hetzel and Welby, 1997).

In calves, 50 mg iodine kg^{-1} of feed DM as calcium iodate reduced body weight gain and feed intake besides the symptoms mentioned above (Newton *et al.*, 1974). But iodine in the form of ethylendiamine dihydroiodide fed at concentrations exceeding 50 mg kg^{-1} feed DM was without adverse effects in calves and lactating cows (NRC, 1980).

4.2. Pigs

Pigs are more tolerant to excess iodine concentrations than other farm animals. Underwood and Suttle (2001) gave tolerances of 300 - 400 mg iodine kg^{-1} DM for pigs. Newton and Clawson (1974) and the NRC (1980) placed the minimum toxic level for growing-finishing pigs (17 kg bw at start, 97 days; calcium iodate) at 400 mg kg^{-1} feed. Although there were no adverse effects on performance, increased thyroid weight and reduced liver iron were observed. In pregnant sows fed 1,500 and 2,500 mg iodine kg^{-1} diet (30 days; KI) no adverse effects on reproductive performance occurred (Arrington *et al.*, 1965).

4.3. Horses

Horses are less tolerant to excess iodine than other farm animals. The maximum tolerable dietary concentration of iodine for horses has been estimated to be 5 mg kg^{-1} DM (NRC, 1980), equivalent to 50 mg of iodine day^{-1} for a horse consuming 10 kg DM daily. However, pregnant mares fed 35 to 48 mg of iodine day^{-1} gave birth to foals with enlarged thyroids due to iodine toxic goiter (Baker and Lindsey, 1968; Drew *et al.*, 1975; Driscoll *et al.*, 1978).

An intake of 40 mg iodine day^{-1} is not far from practice, if iodine rich seaweed (kelp, containing up to 4 g iodine kg^{-1} DM) is included in the diet. When kelp was fed in excess to mares, goiter occured in newborn foals (Schryver, 1990).

In the light of these findings, the maximum tolerable iodine intake set by the NRC (1980) seems too high. The upper tolerated level is likely below 3.5 mg iodine kg^{-1} complete feed.

4.4. Poultry

Signs of toxicosis in laying hen are reduced egg production, egg size and hatchability (Arrington *et al.*, 1967). Peterson (1997) described fertility disturbances in laying hens receiving a diet containing 40 mg iodine kg^{-1}. A recent study (Yalçin *et al.*, 2004) conducted to examine the effects of iodine supplementation of layer diets on production parameters, egg quality and egg iodine content can be considered as tolerance study. 120 laying hens (6 replicates with 20 hens each) were fed balanced diets with 0, 3, 6, 12 and 24 mg iodine as calcium iodate kg^{-1} diet for 30 weeks, respectively. Analytical data confirmed dietary iodine contents with 0.8, 2.9, 5.2, 11.1 and 21.5 mg kg^{-1}, respectively. There were no significant differences among the groups in body weight, feed consumption, egg production, feed consumption per kg eggs, eggshell index, eggshell breaking strength, shell thickness or egg yolk index. Supplementation of the diet to 11.1 mg iodine kg^{-1} increased food consumption per dozen eggs compared to the groups fed the unsupplemented diet and the 5.2 mg iodine kg^{-1} diet. Egg weight was less in groups fed on diets with 11.1 and 21.5 mg iodine kg^{-1} than in the group receiving no iodine supplementation. Iodine supplementation to provide 11.1 and 21.5 mg kg^{-1} reduced egg albumen index and egg Haugh units. The authors concluded that dietary iodine at least up to 6 mg is well tolerated by laying hens. However, Lichovnikova *et al.* (2003) found significant effects on Haugh units, yolk index and eggshell weight at 6.1 mg iodine kg^{-1} feed compared to 3.6 mg kg^{-1}. Therefore this study, even though based on a small number of animals (16 per group), may indicate that the tolerance is below 6 mg kg^{-1}.

In a 20 week study with two commercial turkey strains (100 turkey poults each), Christensen *et al.* (1991) showed that both maternal dietary iodine (0 and 3.5 mg iodine added to 1 kg basal diet containing 0.7 mg iodine kg^{-1}) and hen's breed influenced hatchability of turkey eggs. An interaction of 3.5 mg supplemental iodine kg^{-1} with the breeder strain was observed concerning the body weight of the embryos. The data may indicate that iodine tolerance in turkey hens could be lower than 4.2 mg iodine kg^{-1}. However, no analyses on iodine content of the feed were performed. Since differences observed were small and not always significant, a clear overall picture could not be obtained.

4.5. Fish

Studies (Schuhmacher *et al.*, personal communication) with rainbow trout *(Oncorhynchus mykiss)* and common carp *(Cyprinus carpio)* fed graded levels of supplemented iodine (0-64 mg kg^{-1} feed) observed no effects on performance and histomorphology of the thyroid gland even at the highest dietary concentration (64 mg iodine kg^{-1}). Columnar epithelial cells, as signs of epithelial hypertrophy, or a proliferation of epithelial cells indicating hyperplasia were not observed. Similarly, no effects were seen on fish growth (weight and length) or plasma hormone (thyroxin (T_4) and triiodo-thyronine (T_3)) concentrations in Atlantic salmon (*Salmo salar*) fed graded levels of iodine (10-86 mg kg^{-1}) for five months (Julshamn *et al*., personal communication).

4.6. Dogs and Cats

Belshaw *et al*. (1975) measured iodine concentrations in several commercial brands of dog feed and calculated daily intakes of 0.027-0.085 µg iodine kg^{-1} bw day^{-1} in adult dogs, corresponding to approx. 1-4 mg iodine kg^{-1} feed DM. These feeds were fed without any clinical abnormalities in dogs.

Castillo *et al*. (2001) reported evidence of depressed thyroid gland function confirmed by reduced plasma concentrations of thyroid hormones and bone abnormalities in puppies fed diets providing an estimated maximum iodine intake of 0.25 µg kg^{-1} bw day^{-1}. Bone abnormalities have been found when 0.775 µg kg^{-1} bw day^{-1} (15 fold of the recommendation) were given; abnormalities (mainly reduced hypertrophied cartilage) were associated to hypothyroidism induced by excess iodine (Castillo *et al*., 2001). Based on this information a safe upper limit of iodine for adult dogs can not be given.

Kyle *et al*. (1994) evaluated thyroid function in cats fed a diet containing 5.9 mg iodine kg^{-1} feed DM for 5 months. They did not observe any clinical abnormalities. Free thyroxine concentrations in the serum remained in the normal range, suggesting that consumption of a diet with 5.9 mg iodine kg^{-1} has no negative effects on thyroid function. A significant depression of the serum free thyroxine concentration was observed when a diet containing 13.8 mg iodine kg^{-1} was fed (Tartelin and Ford, 1994). Based on these data it is probable that the safe upper limit for dietary iodine in cat feed is at least 6, but less than 13.8 mg kg^{-1} DM.

4.7 Other species

No data were available for sheep, goats and rabbits.

4.8. Conclusion

Under practical conditions using common feedingstuffs, excess of iodine intake is rather unusual. Only if large amounts of feedingstuffs high in iodine or excessive supplemental iodine are fed tolerance levels may be exceeded.

Pigs and fish are more tolerant than other species. Horses are considerably less tolerant to excess iodine. New studies on iodine tolerance, taking into account modern breeding and feeding methods are scarce.

However, based on the limited available data, the following upper tolerated levels may be estimated: Pigs: 300 mg kg^{-1} feed, horses: < 3.5 mg kg^{-1} feed, laying hens: $\leq$ 6 (> 3.6) mg kg^{-1} feed, dogs: ≥ 4 mg kg^{-1} feed, cats: ≥ 6 (< 13.8) mg kg^{-1} feed. Neither systematic studies nor practical experience on the toxicity of excess dietary iodine concentrations exist for the different fish species. However, there is indication that trout/carp tolerate 64 mg kg^{-1} feed and salmon 86 mg kg^{-1}. The results of the one available study with turkey breeder hens are too inconclusive to allow setting an upper tolerance level.

The standard upper value for dairy cows is considered as 50 mg kg^{-1} complete feed. There is a single observation showing a negative effect in the progeny of cows fed as low as 3 mg iodine kg^{-1} complete feed. But serious doubts remain about the conclusiveness of this data set because the effects on progeny were not specific for iodine toxicity. There is insufficient data on calves to establish a safe upper iodine level. No data is available for sheep, goats and rabbits.

Updated information on iodine tolerance is required, considering current techniques of farm animal rearing, modern breeds (including their progeny) and analytical methods for iodine and more sensitive biomarkers of iodine supply (e.g., thyroid histology). Such studies should lead to specific recommendations for upper tolerated dose levels based on more conclusive scientific data.

5. Iodine in foodstuffs

The iodine content of food differs depending on geographical, soil and agronomic conditions. However in case of food from animal origin it is also influenced by the iodine supply of animals.

5.1. Iodine content of food of plant origin

Iodine concentration in plants depends on the iodine content of soil and water and some geochemical factors. It is usually below 50 µg kg^{-1} fresh matter.

Table 1A (Annex 1) shows data of some food of plant origin, but data base is often not enough to give reliable information. Values range from 10 to 70 µg kg^{-1} in cereals, from 10 to 100 µg kg^{-1} in vegetables, from 20 to 60 µg kg^{-1} in legumes and from 5 to 50 µg iodine kg^{-1} in fruits with very few exceptions of higher values.

5.2. Iodine content of food of animal origin

Iodine concentration in milk, egg, meat and other body tissues depends on iodine concentration of feeds and iodine intake (see Annex 1). In grazing animals iodine from top soil may also contribute (Binnerts, 1979). Principally dietary iodine exerts remarkably less influence on iodine in meat than on iodine in milk or eggs.

5.2.1. Milk

Annex 1 (Table 2A) summarizes iodine concentration in ruminant milk. Levels below (10 to) 20 µg L^{-1} can be attributed to inadequate iodine intake (Groppel and Körber, 1985; Mc Dowell, 2003). In sheep, concentrations below 80 µg L^{-1} point out a probable deficiency state (Mc Dowell, 2003).

Hamann and Heeschen (1982) published comprehensive data on milk iodine in Germany. 111-136 µg iodine L^{-1} milk can be considered as average values for 1980-1981. Minimum values were 38 µg, maximum 1190 µg L^{-1} milk in a total of 1316 samples (herd milk, bulk milk and dairy plant milk). Hampel and Zöllner (2004) discuss 178 µg iodine L^{-1} milk (median value) for Thuringia (Federal state of Germany) in 2002. Considering also other values of Annex 1 Table 2A, 100-300 µg iodine L^{-1} milk could be expected as probable mean value.

A recent Czech study (Kursa *et al.*, 2004) reports that iodine content in bulk milk samples from 187 farms was 324 µg L^{-1}; however, the range was very broad, with 4.3% <20 µg L^{-1} and 18.7% >500 µg L^{-1}. The average milk iodine concentration was more than double that observed in 1997-99, before the introduction of iodine supplementation. Nevertheless, the paper does not present data to establish a relationship between iodine milk content and levels of feed supplementation.

Data from year 2000 on iodine content of low-fat milk from 19 locations in Norway (Dahl *et al.,* 2003) showed that iodine content was higher in the winter (mean 232, range 103-272 µg L^{-1}) than in the summer (mean 88, range 63-122 µg L^{-1}). This study also reports that the levels have increased from those reported in the year 1971, but seasonal differences still exist (winter, 120 µg L^{-1}; summer, 65 µg L^{-1}). The higher iodine content in winter milk is attributed to the iodine fortification of cow's complementary feed during that season.

Studies in Germany also indicate an increase in iodine concentration of cow's milk during the last years (Jahreis *et al*., 1999; Bader *et al*., 2003). The increased iodine concentration in cow's milk were explained by several authors (Anke *et al*., 1998, Jahreis *et al*., 2001) by the intensified use of iodised mineral-mixtures for dairy cows, but regional differences still exist (see Annex 1, Table 2A).

In a recent study, Lindmark-Månsson *et al.* (2003), a number of milk composition parameters were studied on samples taken from nine Swedish dairy plants during 1995-1996. Iodine content of bulk milk (mean 140 µg kg^{-1} or L^{-1}) has experienced a 80% increase from 1975, that can be explained by the higher amount of iodine given to cows due to the increasing amounts of rapeseed used for cow feeding.

Data from UK indicate as well an increase from 150 µg L^{-1} in 1991/92 to 311 µg L^{-1} in 1998/99 (MAFF, 2000).

There exist older regression equations published by Binnerts (1958) and Alderman and Stranks (1967) but no more recent equations have been developed.

The Binnerts polynom shows that iodine content of milk (µg 100 mL^{-1} milk) = $1.5 + 17.5x - 0.6\,x^2 - 0.008\,x^3 - 0.000007\,x^4$, where x is iodine intake (x=actual daily intake of iodine in mg divided by 100). Alderman and Stranks (1967) found a linear correlation with the term milk iodine (µg kg^{-1}) = $2.13x + 3.1$, where x is iodine intake (mg day^{-1}). Table 4 gives expected milk iodine levels calculated according to both formulas at varying dietary iodine concentration.

The polynomial equation seems to better reflect physiological relations, indicating an increasingly smaller percentage of iodine excretion via the milk with higher iodine supply. There might be today also a higher dilution factor in total milk because of higher milk yield (Haman and Heeschen, 1982; Falkenberg *et al.*, 2002).

Table 4. Expected milk iodine calcutated with different formulas

Feed intake (kg DM day^{-1})	10	10	10	10	10	10	10	20	20	20	20	20	20	20
mg iodine kg^{-1} DM	0.6	1.0	1.5	2.0	4.0	6.0	10	0.6	1.0	1.5	2.0	4.0	6.0	10
µg iodine L^{-1} milk (Binnerts, 1958)	25	32	41	50	84	118	184	36	50	67	84	151	216	340
µg iodine L^{-1} milk (Aldermann and Stranks, 1967)	16	24	35	46	88	131	216	29	46	67	88	174	259	429

Hamann and Heeschen (1982) pointed out that in addition to iodine feeding region, the use of disinfectants, udder cleaning, milking, milking machines brand, herd size, milk production and season influence milk iodine concentration.

Preiss *et al*. (1997) measured the highest iodine concentration in milk during March, April, November and December, in which the lowest milk yield was registered. With increasing size of the dairy operation and milk yield a decrease of milk iodine could be measured (Haman and Heeschen, 1982). Also Falkenberg *et al*. (2002) described a negative correlation between the milk yield and the iodine content. Wet udder cleaning (123 µg iodine L^{-1} milk) led to lowest milk iodine, compared to dry cleaning (132 µg iodine L^{-1}) and absence of udder cleaning (180 µg iodine L^{-1}) (Hamann and Heeschen, 1982).

Falkenberg *et al*. (2002) described an increase of the iodine concentration by predipping teats with iodine containing disinfectants. Effects of teat dipping have still to be fully clarified. Aumont (1987) and Galton *et al.* (1986) observed an increase (1–8 times higher) in milk iodine content after use of an iodophore containing teat-dipp. This is in contrast to Galton (2004) where no differences with regard to iodine content in milk were observed. However, there is an interaction between the type of milking machine and the influence of teat dipping on milk iodine (Haman and Heeschen, 1982). This may mask the potential influence of iodine from teet dipping solutions in herd samples. Whereas Hamman and Heeschen (1982) found no influence of teat dipping on milk iodine in herd samples, in a controlled experiment with a teat disinfectant containing 0.5 % iodine, milk iodine increased by 122 µg L^{-1}.

Iodine containing teat dipping solutions are also today widely used. Among the premium label teat dipping preparations in Germany (German Agricultural Society (DLG) seal of quality), about half contain iodine, udder ointments are said to be free. The todays iodine content of teat dipping perparations may vary between 0.1 and 0.5

%, as iodine sources polyvinyl-pyrrolidone-iodine and nonoxinol(9)-iodine are predominantly used.

The use of iodine containing preparations for cleaning and disinfection of milking machines lead to a mean increase of herd milk by 52 µg L^{-1} (Hamman and Heeschen, 1982).

5.2.2. Edible tissues

The iodine content varies between various tissues and depends on supplementation of feeds. It is difficult to give average values because of various influencing factors (Annex 1, Table 3A). Samples from Lithuania show that beef muscle contains about 173 µg iodine kg^{-1} dry tissue (equivalent to 52 µg kg^{-1} fresh tissue (30 % DM)). Pork muscle of unsupplemented control contained about 28 µg iodine kg^{-1} fresh tissue (equivalent to 93 µg kg^{-1} dry tissue (30 % DM), He *et al.,* 2002, Kaufmann and Rambeck, 1998)). Feed supplementation of 5 and 8 mg iodine kg^{-1} resulted in an increase to about 62 and 73 µg iodine kg^{-1} fresh tissue, respectively (equivalent to 207 and 243 µg kg^{-1} dry tissue (30 % DM), respectively). Unsupplemented poultry feed lead to comparable values in breast muscle as in pork muscle. However, adding 1 and 10 mg iodine kg^{-1} feed resulted in about 73 and 344 µg iodine kg^{-1} dry tissue, respectively (equivalent to 22 and 104 µg kg^{-1} fresh tissue (30 % DM), respectively).

5.2.3. Eggs

The iodine content of eggs is also related to the dietary iodine intake of laying hens (Annex 1, Table 5A). Egg yolk contains much more iodine than egg white.

Supplementing the diet with 5 mg iodine kg^{-1} increases the iodine content in the egg yolk from 7 to 50 µg iodine egg^{-1} (Kaufmann and Rambeck, 1998). The iodine content in eggs was even higher, when iodine rich algae were supplemented to the diet. Addition of 0.15 % algae (*Laminaria digitata*, 4 g iodine kg^{-1} DM) increased the iodine content to 145 µg per egg (Ungelenk, 2000). Souci *et al*. (2000) indicate average concentrations of 97, 75-158 and 68 µg kg^{-1} total egg, egg yolk and egg white, respectively.

Iodine contents of 0.8, 2.9, 5.2, 11.1 and 21.5 mg kg^{-1} layer diet resulted in 48, 107, 180, 290 and 511 µg iodine kg^{-1} egg albumen, and 443, 664, 1122, 1953 and 3352 µg iodine kg^{-1} egg yolk, respectively (Yalçin *et al.*, 2004).

5.2.4. Seafood

Food of marine origin (sea fish and shell fish) represents the main natural source of dietary iodine in most instances. The iodine content of marine fish (µg kg^{-1} fresh matter) can vary from 163 in sole to 3180 in haddock and from 308 in crab to 1300 in shrimps (Wayne *et al.*, 1964). The Scientific Committee on Food (SCF) (2002) gave values for marine fish (mean 1220-2500 µg kg^{-1}), shell fish (mean 798-1600 µg kg^{-1}), marine algae (1000-2000 mg kg^{-1}). Annex 1, Table 4A shows further iodine values for marine fish which are extremely variable.

5.3. Other Iodine Sources

Important additional sources of iodine are iodine-enriched foods among which the most important is iodized salt; tablets of iodine or of multiminerals containing iodine as measures ensuring iodine supplementation; iodinated skin disinfectants and many drugs and iodinated X ray contrast media. Hampel and Zöllner (2004) describe for Germany an increase in the consumption of supplementary food (50 – 225 µg iodine per tablet), and a significant uptake from other beverages, including fruit juices (281-336 µg L^{-1}), multivitamin juices (185-550 µg L^{-1}) and iced tea (263 µg L^{-1}).

5.4. Conclusions

Among food from terrestrial animals milk and eggs show highest iodine concentrations, followed by inner organs (kidney, liver, heart), meat showing lowest iodine levels.

Milk iodine originates from number of sources, feed being only one of them. For instance, the use of iodated disinfectants may contribute to the total iodine concentration.

Marine fish/sea food shows the absolute highest iodine concentrations.

6. Iodine and human health

The impact of iodine deficiency and excess on human health has been extensively studied and documented. The present chapter focuses only on the issues necessary to develop the risk assessment described within chapter 7.

Human iodine deficiency leading to endemic goiter has been a recognized public health problem in many inland areas of Europe (e.g., the Alps).

Iodization of salt for human food consumption is the strategy internationally recommended in order to reach the goal of sustainable elimination of iodine deficiency. Moreover, other complementary sources of iodine can include foods from animals reared with iodine-supplemented feeds.

Whereas, to date, endemic goiter has almost disappeared in Europe, the available scientific evidence, evaluated by EU and other international bodies, points out that subclinical iodine deficiency is still a potential widespread problem in Western and Central Europe as it concerns 13 of the 31 countries of this region and 64 % of its population (Delange, 2002; Vitti *et al*., 2003).

The main health risks associated with subclinical iodine deficiency are impaired thyroid function during pregnancy and the neonatal period, that may in turn lead to impaired neurobehavioual functional development.

Data on the recommended dietary intake of humans is given in Annex 2.

6.1. Upper limit of iodine intake

In 1994, in a phase of great attention towards the goal of sustainable elimination of iodine deficiency around the world, WHO stated a tolerable upper intake level (UL) of 1 mg day^{-1} (WHO, 1994). This UL was subsequently questioned because side effects of iodine supplementation were reported at iodine intake levels lower than UL (Todd *et al.,* 1995). In 2001, the SCF and other bodies (such as the IOM) evaluated new figures for different age groups (Table 5). Moreover, populations affected by iodine deficiency should be considered as more sensitive to the adverse effects of iodine intake.

Therefore, based on extensive review of the literature and considering the particular situation of Europe in terms of past history of iodine deficiency and, consequently, of higher risk of both hyper- and hypothyroidism in case of acute or chronic exposure to high doses of iodide, the SCF proposed lower figures as shown in Table 5, especially for young adults for whom an UL of only 500 µg has been recommended.

Table 5. **Tolerable upper intake level (UL) in healthy populations (µg I day^{-1}) as proposed by IOM US Academy of Sciences (2001) and SCF (2002)**

IOM US Academy of Sciences (2001)		SCF (2002)	
Age	**UL (µg I day^{-1})**	**Age**	**UL (µg I day^{-1})**
0 – 12 months	Not possible to establish	1 – 3 years	200
1 – 3 years	200	4 – 6 years	250
4 – 8 years	300	7 – 10 years	300
9 – 13 years	600	11 – 14 years	450
14 – 18 years	900	15 – 17 years	500
> 19 years	1100	Adults	600
Pregnancy	900	Pregnancy, Lactation	600

6.2. Adverse effects of iodine excess in humans

Adverse effects of iodine excess in humans are summarized in Table 6. Acute and massive excess of iodide can inhibit the process of synthesis of hormones by the thyroid gland through an inhibition of the process of iodide organification, the so-called Wolff-Chaikoff effect. The Wolff-Chaikoff effect occurs as soon as the ratio of intrathyroidal iodide to organic iodine reaches a critical level. Thus, the risk increases when iodine stores of the thyroid gland are low, such as in neonates and young infants in Europe.

Table 6. **Adverse effects of iodine excess in humans**

Iodide goiter and iodine-induced hypothyroidism
Coastal endemic goiter in Japan-China. Consumption of seaweeds
Neonates following maternal iodide overload (Wolff-Chaikoff effect)

Iodine-induced hyperthyroidism (IIH)
Main complication of iodine prophylactic due to the development of autonomous thyroid nodules with activation mutations of the TSH receptor

Iodine-induced thyroiditis
Iodine stimulates thyroid autoimmunity, which is depressed in iodine deficiency but which is “reset to normal” after correction of iodine deficiency

From Delange and Dunn (2004); Delange and Lecomte (2000); Braverman (1998).

Iodine-induced hyperthyroidism (IIH) - due to the development of autonomous thyroid nodules, with activation mutation of the TSH receptors, that loose their autoregulation mechanism and can produce as much thyroid hormones as they receive iodide (Dremier *et al.*, 1996) - has been described in most of the iodine deficient parts of the world following the introduction of iodine supplementation (Stanbury *et al.*, 1998). These cases of hyperthyroidism induced by iodine occur most usually in older adults with longstanding iodine deficiency and autonomous thyroid nodules. The occurrence of this complication is usually of short duration in a given country and disappears after a few years, but it can be a very serious health problem with a particularly high risk of tachyarrythmia (Todd *et al.*, 1995).

Another possible adverse effect of iodide is the aggravation or even the induction of autoimmune thyroiditis. From the literature (see Delange and Lecomte, 2000), it can be concluded that iodine deficiency decreases thyroid autoimmunity and that the correction of iodine deficiency "resets" the frequency of thyroid autoimmune processes at a "normal" frequency. The frequency of autoimmune thyroiditis is much greater in the United States than in Europe because the iodine intake is much higher in the U.S. than in Europe (Delange and Hetzel, 2003).

Overall, the adverse effects of iodine, including those observed following iodine supplementation, have a low incidence. All available evidence indicates that the benefits of correcting iodine deficiency in human populations by far outweigh its risks (Braverman, 1998; Delange, 1998).

All available estimates of iodine dietary intake in Europe indicate that actual iodine concentrations in foods of animal origin are far lower than theoretical estimates; moreover, available data do not support an association between current levels of iodine feed supplementation, which are considerably lower than the upper iodine levels approved in feed by Directive 70/524/EEC, and risks of excessive iodine intake in humans (Großklaus and Jahreis, 2004).

6.3. Conclusion

Subclinical iodine deficiency is still a potential widespread problem in Western and Central Europe. Up-to-date figures on iodine recommendations are available (see Annex 2). The UL of iodine is about 2 to 4 times higher than the recommended level.

Adverse effects of iodine excess in humans are well documented and occur mostly following iodine supplementation or consumption of specific foods (e.g., certain seaweeds). The main adverse effect is the development of hyperthyroidism, which is transient in most cases. The risk is considered low and definitely outweighted by the benefits of correction of iodine deficiency.

Available evidence indicates that adverse effects of iodine excess in humans are unlikely to occur following the consumption of foods from farm animals. Available data do not support an association between current levels of iodine feed supplementation which are far lower than maximum allowed limits, and risks of excessive iodine intake in humans.

7. Risk assessment for consumer health

Foods of plant origin present in the European diet are, alone, unlikely to provide an adequate dietary intake of iodine (see Annex 1, Table 1A). In fact numerous articles exist on the danger of iodine deficiency for vegetarians and even higher for vegans (Krajkovicova *et al*., 2003; Lentze, 2001). The intake of iodine from plant material is therefore not considered further.

7.1. Intake with food of animal origin

Foods of animal origin are recognized as an important dietary source of iodine. The contribution of individual food items is related to both environmental factors and dietary lifestyles in different European areas. Recent data indicate that for Germany milk and dairy products provide on average 37 % and meat and meat products 21 % of dietary iodine, whereas fish (9 %) provides a fraction significantly smaller than bread and cereal-based foods (19 %) (Jahreis *et al.,* 2001). In the Danish population, more than 44 % iodine comes from the milk (Rasmussen *et al.,* 2002).

Age-related nutritional patterns need to be considered. A Swiss pilot study showed that milk represented 40-50% of iodine intake for children during winter. This proportion was more than two-fold higher than in adults, which have more varied dietary habits (Als *et al.*, 2003). In Dutch schoolchildren, seafood was a minor source of iodine, since, on average, it was consumed only once a month (Wiersinga *et al.*, 2001).

7.2. The contribution of iodine-supplemented feeds to human dietary intake

An application of the very conservative consumption model as described in Directive 87/153/EC is not possible because of lack of sufficient data from animal experiments in which the highest iodine level approved has been fed.

For beef an estimated contribution (300 g muscle, 100 g liver and 50 g kidney; fed iodine at levels around 1 mg/recommended levels) of 60 µg, for pork (fed diets with 8 mg iodine kg^{-1}) of 42 µg, and for poultry (300 g muscle, 100 g liver, 10 g kidney; fed diets containing 10 mg iodine kg^{-1}) of 70 µg can be estimated, however with a level of uncertainity. It is concluded from these worst case estimations, that iodine intake from beef, pork or poultry would not exceed 100 µg day^{-1} for an adult person and is probably nearer to 50 µg day^{-1}. Further estimates will therefore be limited to model calculations primarily with milk and eggs.

Fish is not considered, because the iodine content of farmed fish fed diets with about 20 mg iodine kg^{-1} (highest level approved) is still below the iodine in marine fish (Schuhmacher *et al.*, personal communication; Julshamn, personal communication).

7.2.1. Milk

1.5 L milk of cows fed 20 kg complete feed with 10 mg iodine kg^{-1} may contain between 510 and 645 µg iodine (calculated from the figures given in Table 4). This amounts to 85-108 % of the UL of adults. For adolescents (11-14 years) 510 and 645 µg from milk clearly exceeds the UL (450 µg). Assuming that 4-6 years old children consume daily 0.5 L milk, the UL (250 µg) will nearly be matched (170-215 µg) or in fact also exceeded if iodine from other sources is added. A comparable calculation for milk from cows fed 6 mg iodine kg^{-1} diets shows for adults an uptake of 324-389 µg iodine, which is considerably below the UL (max. 65 %). For adolescents, the iodine intake by 1.5 L milk is at about 72-86 % of the UL. 0.5 L milk for 4-6 years old children will contribute to 43-52% of the UL.

7.2.2. Eggs

Iodine from eggs is calculated based on the data of Yalçin et al. (2004). For layer diets containing 10 mg iodine kg^{-1}, the experimental data obtained with 11.1 mg iodine kg^{-1} are used, for 5 mg iodine kg^{-1}, the data obtained at 5.2 mg iodine kg^{-1}. This results in 84 µg iodine 100 g^{-1} egg content for the highest dietary iodine approved. When diets with 5 mg iodine kg^{-1} are fed, 50 µg can be expected in 100 g egg content. These figures amount to 14-10 % of the UL for adults and to 19-11 % of the UL for 11-14 years old adolescents.

One egg (60 g) of layers fed diets with 5 mg iodine kg^{-1} would contain about 27 µg iodine. This is equal to 11 % of the UL of 4-6 years old children.

7.2.3. Milk and eggs

Different worst case iodine intake situations are calculated on the basis of the above data with 6 (dairy cow) and 5 mg iodine (laying hen) kg^{-1} feed in diets for adults, adolescents and 4-6 years old children for milk and eggs. Milk and egg model consumption of adults (1.5 L milk, 100 g egg content) will achieve with 440 µg iodine 73 % of the UL, adding another 100 µg from meat, the figure would increase to 90 %. Assuming an intake of 9 g iodised salt (about 180 µg iodine), the UL would be exceeded by 20 %. The same calculation for adolescents with a reduced UL leads to an iodine intake of 98 % of the UL not giving the opportunity for meat and iodised salt consumption.

However, sensitive 4-6 year old children would consume with 500 mL milk and one egg about 63 % of the UL (157 µg), based on the consumption of 250 mL milk and a half egg only 79 µg (32 % of the UL).

Table 7 presents the same model calculation for diets with 4 mg iodine kg^{-1}. The data indicate a sufficient margin of safety.

Table 7. Iodine intake from milk and eggs (complete feed: 4 mg iodine kg^{-1})

	Adults	Adolescents	4-6 years old children	
Food intake	1.5 L milk, 100 g egg	1.5 L milk, 100 g egg	500 mL milk, 1 egg (54 g)	250 mL milk, 0.5 egg (27 g)
Iodine intake (µg)	300	300	109	55
% of UL	50	67	44	22

All above estimates do not include other external factors also influencing milk iodine (e.g. udder hygiene, teat dipping, disinfection of the milking machine etc.).

7.3. Other iodine sources of human dietary intake

Supplemented feeds are not the single, nor possibly the major source, of iodine in human diet. Iodine-enriched salt, supplemented food items (including iodine rich algae), and several beverages (iced tea, fruit juices, multivitamin drinks) may all contribute to the overall iodine intake. Such intake patterns may differ among European areas as well as being strongly influenced by individual behaviour and preferences, and are difficult to estimate. Consequently, it is difficult to estimate the relative contribution of iodine passing in foods by iodine-supplemented feeds.

7.4. Conclusion

Foods of animal origin are an important iodine sources in human nutrition. In general, their iodine content depends on the type of food and iodine supplementation of animal feed. There are insufficient data to characterize the contribution of feed supplementation to human iodine intake through different foods of animal origin. Therefore, a reliable estimate of the human iodine intake deriving from feed supplementation has yet to be performed.

However, all available data on iodine concentrations in foods of animal origin as well on dietary intake in Europe do not support an association between current practice levels of iodine feed supplementation (1-2 mg kg^{-1} farm animal feed, up to 10 mg kg^{-1} fish feed) and risks of excessive iodine intake in humans.

Model calculations (worst case scenarios) with milk and eggs only show, that utilizing the approved upper limits of iodine (10 mg kg^{-1}) in feed could result in exceeding the UL for adults and adolescents and approximately matching the UL for 4-6 years old children. Reducing iodine to 4 mg kg^{-1} feed for dairy cows and laying hens would result in a satisfactory margin of safety for adults, adolescents and 4-6 years old children.

8. Effects on environment

Iodine is a naturally occurring element. Its content in soil depends on geological origin. Lowest iodine concentrations are found in granites, highest contents in boulder clay (Anke *et al.,* 1993). The iodine content ranges from 6 to 10 mg kg^{-1} for soils derived from igneous rocks, from 2.2 to 4.5 mg kg^{-1} in soil derived from sedimentary rocks ranges and is app. 5 mg kg^{-1} in soil from all types of metamorphic rocks. In soils from Germany the iodine content was 2.4 mg kg^{-1} in a loam soil, 3.2 mg kg^{-1} in a sandy loam soil, 3.6 mg kg^{-1} in a loamy sand soil and 1.8 mg kg^{-1} in sand. In Ireland peaty soil contained 32 mg iodine kg^{-1}, soil derived from limestone and red sandstone contained 3.5 and 2.4 mg iodine kg^{-1}, respectively (Anon. 1956). The iodine concentration in 42 soils in Co Wexford Ireland ranged from 3 - 30 mg iodine kg^{-1}. Loam and clay-loam soils had consistently higher values that loamy sand-sandy loam soils. The average iodine concentration in soil increased in the order loamy sand 3.73 mg kg^{-1} < sandy loam 4.74 mg kg^{-1} <sandy clay loam 6.26 < loam 12.17 mg kg^{-1} < clay loam 19.01 mg kg^{-1}. Iodine concentration was not related to distance from the sea (McGrath and Fleming, 1988). In rainwater the iodine concentration is around 1 $\mu g\ L^{-1}$.

The forms of aqueous iodine found in natural environments are dependent on pH and electrochemical potential (Eh). The dominant forms are the inorganic species iodate (IO_3^-), iodide (I^-), and molecular iodine (I_2). Thermodynamically, under typical pH and Eh ranges found in natural soil environments, I^- should be the most prevalent phase, while IO_3^- exists under more oxidizing conditions. Soil solution measurements support thermodynamic predictions in that I^- is the prevalent form in soil solutions under most conditions and IO_3^- is usually only present in soil solutions associated with oxidized conditions found in alkaline desert soils. Soil solution I^- sorbs to soil clays, hydrous oxides, and soil organic matter, where sorption generally increases with decreasing pH. In alkaline soils, I^- is mobile and has even been evaluated as an inert tracer in soil water studies (as reviewed by Mackowiak *et al.,* 2004).

Only few toxicity data are available for any of the iodine species on soil and aquatic organisms. In general iodate appears to be less toxic than iodide. In solution culture studies with rice (*Oryza sativa*), leaf chlorosis was observed at 10 µM I^-, while 100 µM IO_3^- had only minor effects (Mackowiak and Grossl, 1999). Fish appear not be very sensitive to I^- and IO_3^- with LC_{50} for rainbow trout > 200 and 850 mg L^{-1}, respectively. *Daphnia magna* are more sensitive to I^- (LC_{50} < 0.2 mg L^{-1}) than to IO_3^- (LC_{50} > 10 mg L^{-1}). Unlike the I_2 form, iodide and iodate has very low antibacterial activity.

8.1. Risk characterisation

Iodide or iodate in feed can enter the environment via direct excretion of dung or urine on pasture or spreading of sludge and slurry collected from intensively reared animals. Based on the calculation method used for zinc as feed additive by SCAN[1] (2003), the maximum increase of iodine in soil for the main categories of target animals is around 80 μg kg^{-1}, which is related to an application rate of 170 kg N ha^{-1} after one year assuming that 100% of a dose of 4 mg kg^{-1} feed will be excreted. This concentration is well below the background concentration and it is therefore not expected to pose an environmental risk.

CONCLUSIONS AND RECOMMENDATIONS

Iodine salts are authorized under Directive 70/524/EEC concerning additives in feedingstuffs under the category "trace elements". Maximum iodine concentrations in feeds authorized are 4, 20 and 10 mg kg^{-1} feed for horses, fish and all other species, respectively.

Conclusions

The iodine requirements and allowances for various food-producing species vary between 0.1 and 0.7 (1.1 for fish) mg kg^{-1} of feed. Cats have higher requirements. The requirements are influenced by physiological demands for growth, reproduction or lactation. Other factors (e.g., temperature, dietary goitrogens) may increase the iodine requirement.

Based on a review of the iodine content of common feedingstuffs, iodine supplementation of practical diets for food producing and companion animals is necessary in most cases.

Based on the limited available data basis, with respect to animal safety the following maximum dietary iodine levels, 3 mg kg^{-1} feed for horses, 5 mg kg^{-1} feed for laying hens, 4 mg kg^{-1} feed for dogs and 6 mg kg^{-1} feed for cats, should not be exceeded. The iodine tolerance of pigs and fish is far above the existing levels permitted under EU regulations. The proposed upper limits are 3 to 10- fold higher than the current recommendations, allowing sufficient compensation for potential goitrogenic substances in feed. At present the upper safe level for dairy cows can not be determined, data vary between 50 mg and as low as 3 mg kg^{-1} complete feed. No data is available for chickens for fattening, turkeys, rabbits, sheep and goats.

Among food from terrestrial animals milk and eggs show highest iodine concentrations, followed by organs (kidney, liver, heart), meat showing the lowest iodine levels. Milk iodine originates from number of sources, feed being only one of them. For example, the use of iodated disinfectants in dairy farming may contribute to the total iodine concentration.

Sea food has the absolute highest iodine concentrations.

Although the main effect of human iodine deficiency, i.e., endemic goiter has almost disappeared in developed Countries, EU and other international bodies point out that subclinical iodine deficiency may still persist as a widespread problem in large parts of Western and Central Europe.

Up-to-date figures on iodine recommendations for humans are available. The UL of iodine is about 2 to 4 times higher than the recommended level.

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[1] Opinion of the Scientific Committee for Animal Nutrition on the use of zinc in feedingstuffs, adopted on 14 March 2003 http://europa.eu.int/comm/food/fs/sc/scan/out120_en.pdf

Adverse effects of iodine excess in humans are well documented and occur mostly following the direct intake of iodine supplements or consumption of specific foods (e.g., certain seaweeds). The main adverse effect is the development of hyperthyroidism, which is transient in most cases.

Available evidence indicates that adverse effects of iodine excess in humans are unlikely to occur following the consumption of foods from farm animals. However, it should be noted that the upper iodine levels approved in feed by Directive 70/524/EEC are not currently used in feed manufacturing practise, the actual range used lies between 1 and 2 mg kg^{-1} feed for farm animals. All available estimates of iodine dietary intake in Europe indicate that actual iodine concentrations in foods of animal origin are far lower than theoretical estimates. Moreover, available data do not support an association between current levels of iodine feed supplementation and risks of excessive iodine intake in humans.

Not enough data, particularly from dose response studies are available to reliably estimate the iodine content of the different tissues of food producing animals, on which a very conservative consumption model for risk assesment is usually based (Directive 87/153/EEC). However, the contribution of edible tissues to human iodine supply is low compared to milk. Supplementing diets of farmed fish with 20 mg iodine kg^{-1} will result in lower tissues concentrations than found in wild marine fish.

Model calculations (worst case scenarios) with milk and eggs only show that utilizing the approved upper limits of iodine (10 mg kg^{-1}) in feed could result in exceeding the UL for adults and adolescents and approximately matching the UL for 4-6 years old children. Reducing iodine to 4 mg kg^{-1} for dairy cows and laying hens would result in a satisfactory margin of safety for adults, adolescents and 4-6 years old children.

FEEDAP Panel stresses the fact that iodine supplemented feeds are not the single, nor possibly the major source, of iodine in the human diet. Iodine-enriched salt, supplemented food items, and several iodine enriched beverages may all contribute to the overall iodine intake.

The predicted concentration in soil resulting from spreading of sludge and slurry collected from intensively reared animals is well below the background concentration and it is therefore not expected to pose an environmental risk.

Recommendations

It should be noted that the basic data for today's knowledge on iodine requirement were obtained many years ago. Significant scientific contributions to our knowledge in the last two decades, also applying more advanced analytical techniques are rather scarce. Iodine requirement in major food-producing species may have changed due to the significant advances in breeding methods, leading to remarkably higher growth rates and a higher meat proportion in the body as well as a higher milk yield. Feed manufacturing techniques also deserve consideration. Most of the available studies do not consider the potential loss of iodine in feed from manufacturing until final consumption.

FEEDAP Panel recommends obtaining more up-to-date information of the iodine requirement in farm animals.

The Panel also recommends that more data on dose-response relationships in major food producing species would be required to assess the resulting iodine content of food of animal origin.

Updated information on iodine tolerance is also required, including more sensitive biomarkers of iodine supply (e.g., thyroid histology). Such studies should lead to specific recommendations for upper tolerated dose levels based on more conclusive scientific data.

ANNOTATION

Finally, the FEEDAP Panel wishes to draw the attention of the Commission to the fact, that iodine containing iodine-based disinfectants (e.g. teat dipping preparations and milking machine disinfectants) may contribute more to total milk iodine than the proposed upper level of 4 mg iodine kg^{-1} complete feed for dairy cows.

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ANNEX 1

Table 1A. Iodine content (µg kg^{-1}) of food of plant origin (Souci *et al.*, 2000)

Food	µg kg^{-1}	Food	µg kg^{-1}
Cereals		**Legumes**	
Buckwheat flour	25	Bean	18
Barley	74	Pea	42
Groats	10	Soyabean	63
Oats	77	Flour	8
Rolled	45		
Groats	45	**Mushrooms**	
Meal	42	Champignon	180
Millet	25	Boletus	36
Corn	26		
Flakes	10	**Fruits**	
Rice unpolished	22	Apple	8.2
Polished	20	Pear	7.7
Flour	10	Apricot	5
Rye	72	Cherry	12
Wheat	67	Peach	29
Grits	51	Plum	14
Bran	310	Blackberry	4
		Strawberry	27
Vegetable		Raspberry	30
Sweet potato	24	Red currant	10
Potato	26	Mountain cranberry	50
Kohlrabi	7.5	Gooseberry	9.2
Swede	40	Grape	9.9
Horse radish	10	Rosehip	10
Carrot	16	Pineapple	2-9.7
Parsnip	36	Orange	8.5
Radishes	12	Avocado	10
Radish	80	Banana	20
Beetroot	4	Date	10
Celeriac	25	Fig	15
Turnip	75	Grapefruit	13
Celery	10	Mandarin	8
Cauliflower	6	Mango	16
Broccoli	150	Ladysfinger	56
Chinese leaves	3	Watermelon	100
Endive	29	Lemon	15
Kale	45	Cantaloupe melon	20
Garlic	27	Cashew nut	100
Lettuce	19	Sweet chestnut	1
Parsley	34	Peanut	130
Leek	86	Hazelnut	15
Rhubarb	23	Coconut	12
Brussel sprouts	7	Almond	20
Red cabbage	29	Brazil nut	0.5
Chives	42	Walnut	30
Asparagus	70		
Spinach	120	**Drinks**	
White cabbage	30	Cocoa powder	31
Savoy cabbage	26	Coffee roast	33
Onion	18	Tea	110
Aubergine	8		
French beans	30	**Yeast**	
Cucumber	29	Baker's	5
Pumpkin	14	Brewer's	40
Green peppers	10		
Tomato	11		
Squash	23		
Sweet corn	33		

Table 2A. Iodine content of milk

Species	Feeding/ iodine supplementation	Milk µg kg^{-1}	References
<u>Cattle</u>			
Farm samples (UK)			Broadhead *et al.*, 1965
Winter	not known	110-210	
Summer		10-20	
Farm samples (Norway)			Dahl *et al.*, 2003b
Winter, low fat	not known	103-272	
Winter, organic		35-365	
Summer, low fat		63-122	
Summer, organic		17-87	
Farm samples (USA)	not known	220	Lacroix and Wong, 1980
Samples from dairy (Germany)	not known	30-60	Wiechen and Kock, 1985
Experiments, various I-supplementation		Day of lactation: 1 / 7 / 14 / 28 / 56	Groppel *et al.*, 1988
	0.09 mg kg^{-1} DM	38 / 21 / 8 / 6 / 8	
	0.73 mg kg^{-1} DM	53 / 39 / 34 / 44 / 44	
		Day of lactation: 1 / 40	
	Control (0.15 mg kg^{-1} DM)	36 / 6	
	+0.92 mg $animal^{-1}$ day^{-1}	45 / 22	
	+1.83 mg $animal^{-1}$ day^{-1}	50 / 30	
	3.67 mg $animal^{-1}$ day^{-1}	51 / 34	
Farm samples before (1985) and after I-supplementation (1987/89) in practice in East-Germany	1985	17 ±10	Anke *et al.*, 1993
	1987	53 ±35	
	1989	81 ±11	
Influence of season (Samples from Bavaria, Germany)			Preiss *et al.*, 1997
January (n=33)	not known	102 (48-188)	
February (n=31)	not known	100 (42-177)	
March (n=31)	not known	119 (60-181)	
April (n=33)	not known	138 (53-298)	
May (n=33)	not known	97 (45-168)	
June (n=32)	not known	111 (24-202)	
July (n=31)	not known	98 (32-181)	
August (n=29)	not known	87 (30-181)	
September (n=29)	not known	84 (26-154)	
October (n=27)	not known	98 (31-171)	
November (n=29)	not known	161 (79-259)	
December (n=30)	not known	180 (80-294)	
Control, I-supplemented 10-18,5 mg I cow^{-1} day^{-1}		114	Ehlers *et al.*, 1994
+30% Rapeseed meal (13 µmol Gluc.) in concentrate		106	
Control, unsupplemented 1,5-6,8 mg cow^{-1} day^{-1}		76	
+30% Rapeseed meal (13 µmol Gluc.) in concentrate		78	

Table 2A continued

Unsupplemented control (~0,2 mg kg^{-1} DM)		20				Herzig *et al*., 1999
+1/3 requirements as KI		50				
as Ethylenediamine dihydroiodide (EDDI)		37				
+2/3 requirements as KI		80				
as Ethylenediamine dihydroiodide (EDDI)		64				
+ requirements as KI		173				
as Ethylenediamine dihydroiodide (EDDI)		121				
Feeding experiment (n=6)	control	130				Kaufmann and Rambeck, 1998
	+ 20 mg cow^{-1} day^{-1}	180				
	+ 60 mg cow^{-1} day^{-1}	400				
	+ 150 mg cow^{-1} day^{-1}	480				
Survey UK						
1995/96		300				MAFF, 1997, 2000
1998/99		311				
Farm samples, same region as Bader *et al*. (2003)	not known	91				Jahreis *et al*., 1999
Farm samples (n=34)	not known	178 (48-661)				Bader *et al*., 2003
Grass silage + concentrate						
Concentrate with (n=8)						
0	0.5 mg /kg DM	271				
15% Crambe cake	0.5 mg/kg DM	142				
30% Crambe cake	0.5 mg/kg DM	117				Kampf *et al*., 2003
0	0.5 mg/kg DM	182				
15% Crambe meal	0.5 mg/kg DM	95				
30% Crambe meal	0.5 mg/kg DM	77				
Farm samples (n=23)	not known	94 (9-189)				Schöne *et al*., 2003
Goat		Day of lactation				Groppel *et al*., 1988
		1	14	28	56	
Experiments, various I-supplementation	0.06 mg kg^{-1}DM	34	5	4	5	
	0.11 mg kg^{-1}DM	465	45	58	55	
	0.63 mg kg^{-1}DM	1252	231	249	228	
		Day of lactation				Groppel *et al*., 1984
		1	14	28	42	
	0.04 mg kg^{-1}DM	18	5	5	6	
	0.13 mg kg^{-1}DM	98	36	34	36	
	0.50 mg kg^{-1}DM	319	216	246	246	
Various regions in South Bohemia						
1998	not known	32 (16-94)				Travnicek *et al*., 2000
1999 (+I-supplementation)		63 (14-103)				
Sheep						
Various regions in South Bohemia	not known	105 (17-437)				Travnicek *et al*. 2000

Table 3A. **Iodine content of edible tissues (µg kg^{-1} DM)**

Feeding/Iodine supplementation			Tissue			References
<u>Bulls</u>			Heart	Liver	Kidney	
Experiments, various iodine supplementation	0.07 mg kg^{-1}DM	(n=9)	24	40	32	Groppel *et al.*, 1990b
	0.15 mg kg^{-1}DM	(n=10)	69	116	112	
	0.23 mg kg^{-1}DM	(n=10)	96	151	159	
	0.39 mg kg^{-1}DM	(n=10)	135	153	196	
	0.71 mg kg^{-1}DM	(n=9)	274	244	341	
	0.20 mg kg^{-1}DM	(n=7)	182	166	194	Groppel *et al.*, 1990b
	0.22 mg kg^{-1}DM	(n=8)	218	205	356	
	0.66 mg kg^{-1}DM	(n=5)	434	356	532	
Farm samples from Lithuania	not known		Muscle	Liver	Kidney	Drebickas, 1993
			173 ±17	70 ±6	61 ±2	
<u>Sheep</u>			Liver	Kidney		Groppel *et al.*, 1990a
	0.1 mg kg^{-1}DM	(n=23)	46	67		
	0.36 mg kg^{-1}DM	(n=5)	117	206		
<u>Goats</u>		(n=11-15)				
		Muscle	Heart	Liver	Kidney	
	0.04 mg kg^{-1}DM	108	46	37	64	Groppel *et al.*, 1990a
	0.40 mg kg^{-1}DM	202	136	180	261	
		(n=11-13)				
	0.06 mg kg^{-1}DM	104	56	60	80	Groppel *et al.*, 1990a
	0.11 mg kg^{-1}DM	112	92	93	129	
	0.63 mg kg^{-1}DM	211	162	214	301	
<u>Pork</u>[1]		Muscle[1]	Heart[1]	Liver[1]	Kidney[1]	Kaufmann and Rambeck, 1998
Feeding experiment (n=12)	Control	23	35	70	210	
	+30 mg I kg^{-1} fresh weight[1]	138	210	370	850	
Feeding experiment (n=12)	Control (0.22 mg kg^{-1})	32	32	53	56	He *et al.*, 2002
	+ 5 mg kg^{-1} (KI)	38	51	86	94	
	+ 8 mg kg^{-1} (KI)	51	63	115	105	
	+ 5 mg/kg (Algae)	86	54	127	97	
	+ 8 mg/kg (Algae)	94	73	164	128	
<u>Poultry</u> Farmyard (home produced fodder; 0.18 mg I kg^{-1})			Liver 23 (16-35) Kidney 27 (22-32) Muscle 6.8 (5.6-8.5)			Stibiij and Holeman, 2002
		Breast m.	Heart	Liver	Kidney	
Experiments, various I-supplementation (n=6)	Control (0.03 mg kg^{-1} DM)	32	354	30	88	Groppel *et al.*, 1991
	+ 0.1 mg kg^{-1} DM (KIO_3)	57	459	45	97	
	+ 1 mg kg^{-1} DM (KIO_3)	73	518	71	126	
	+ 10 mg kg^{-1} DM (KIO_3I)	385	1295	525	558	
	+ 10 mg kg^{-1} DM (KI)	302	1148	901	646	
	+ 100 mg kg^{-1} DM (KIO_3)[2]	1114	5721	5872	5913	
	+ 100 mg kg^{-1} DM (KI)[1]	1248	5479	9184	6385	
<u>Fresh water fish</u>						
Chars			(µg kg^{-1} tissue)			
	Control		Muscle 130 (95-162)			Burkhard *et al.*, 2002
	+0.8 % marine algae (≅ 4 g I kg^{-1} fresh weight algae)		Muscle 530 (435-568)			

[1]expressed µg kg^{-1} fresh weight [2]not authorised under Directive 70/524/EEC

Table 4A. **Iodine content of edible tissues (µg I 100 g^{-1} wet tissue) of marine fish**

Fish species	Karl and Werner, 1998	Bundeslebensmittelschlüssel, 1994	Julshamn *et al*. 2001
Haddock (*Melanogrammus aeglefinus*)	186		60-920
Pollack (*Pollachius virens*)	123	77	23-266
Cod (*Gadus morhua*)	187	133	18-1270
(*Merlangius merlangus*)	138		
Redfish (*Sebastes matinus*)	70	76	10-33
Herring (*Clupea harengus*)	40		14-160
Mackerel (*Scomber scomber*)	115	49	14-120
Atlantic salmon (*Salmo salar*)	45	34	6-34*
Trout (*Oncorhynchus mykiss*)	10	2	
Plaice (*Pleronectes platessa*)	46	41	
Dab (*Limanda limanda*)	66		
Flounder (*Platichthys flesus*)	65		
Hake (*Merluccius merluccius*)		93	
Tuna (*Thunnidae*)		50	
Halibut (*Hippoglossus hippoglossus*)		40	
Greenland halibut (*Reinharftius hippoglossoides*)			4-32
Ling (*Molva molva*)			3-11
Tusk (*Brosme brosme*)			8-32

* Farmed Atlantic salmon

Table 5A. **Iodine content of eggs (µg 100 g^{-1} wet content)**

Feeding/Iodine supplementation	**Edible egg (µg 100 g^{-1})**	**References**
Laying hens		
Control (0.4 mg I kg^{-1} DM)	14	Richter, 1995
+ 0.5 mg kg^{-1}	33	
+ 5 mg kg^{-1}	146	
+ 20 mg kg^{-1} 1)	700	
+ 40 mg kg^{-1} 1)	1067	
Layers	**Egg yolk** 1	
Control (0.6 mg I kg^{-1} DM)	200	Ungelenk, 2000
+ 2.5 mg I kg^{-1} as KJO_3	400	
+ 5.0 mg I kg^{-1}	600	
+ 2.5 mg I kg^{-1} as *Laminaria digitata*	480	
+ 5.0 mg I kg^{-1}	760	
+ 5.0 mg I kg^{-1} as *Ascophyllum nodosum*	600	
Farm samples	**Egg yolk**	
Big Farms, March-June	745	Kroupova, 1997
Nov.-Jan.	822	
Small farms, March-June	135	
Nov.-Jan.	365	
Farmyard (home produced fodder; 0.18 I mg kg^{-1})	Egg yolk 114 White egg 6.7	Stibij and Holcman, 2002
	Edible egg	
Major producer, laying hens	39-52	Dahl *et al.*, 2004
Quails	**Egg yolk** 2, 3 **(21 days of feeding)**	
Control (0.33 mg I kg^{-1} DM)	40	Ungelenk, 2000
+ 1.5 mg I kg^{-1}as KJO_3	370	
+ 3.0 mg I kg^{-1}	970	
+ 5.0 mg I kg^{-1}	1280	
+ 7.0 mg I kg^{-1}	1980	
+ 1.5 mg I kg^{-1} as *Laminaria hyperborea*	350	
+ 3.0 mg I kg^{-1}	890	
+ 5.0 mg I kg^{-1}	1350	
+ 7.0 mg I kg^{-1}	1800	
+ 3.0 mg I kg^{-1} as *Laminaria digitata*	970	
+ 5.0 mg I kg^{-1}	1430	
+ 3.0 mg I kg^{-1} as *Laminaria saccharina*	920	
+ 5.0 mg I kg^{-1}	1370	
+ 0.2 mg I kg^{-1} as Omega algae	130	
+ 0.4 mg I kg^{-1}	200	

1) Expressed on dry matter basis

2) I in white egg < 3% of I-concentration in egg yolk

3) Egg yolk is about 35 % of edible egg in layers, about 40 % in quails

ANNEX 2

Recommended dietary intake of iodine

Table 6A summarizes the recommendations on iodine intake produced by SCF (SCF. Nutrition and energy intakes for the European Community. Opinion expressed on 11 December 1992 (http://europa.eu.int/comm/food/fs/sc/scf/reports/scf_reports_31.pdf) as well as those recently produced by WHO/UNICEF/ ICCIDD (2001), and by the Institute of Medicine (IOM) of the US Academy of Sciences (2001).

Table 6A. **Recommended Dietary Intake of Iodine (μg day^{-1})[a]**

WHO/UNICEF/ICCIDD		US Academy		SCF	
Age/state	Intake	Age/state	Intake	Age/state	Intake
0-59 months	90	0-12 months	110-130	6-11 months	50
6-12 years	120	1-8 years	90	1-3 years	70
Adolesc. + adults	150	9-13 years	120	4-6 years	90
Pregnancy	200	14-18 years	150	7-10 years	100
		Adults	150	11-14 years	120
Lactation	200	Pregnancy	220	> 15 years & adulthood	130
		Lactation	290	Pregnancy, lactation	130–160

[a] Adapted from WHO/UNICEF/ICCIDD. WHO/NHD/01.1, 2001 and Institute of Medicine. US Academy of Sciences, 2001, SCF